



Jet Propulsion Laboratory
California Institute of Technology

Aerosol profiling using radiometric and polarimetric spectral measurements in the O₂ A-band

Myungje Choi¹, Dejian Fu¹, Stanley P. Sander¹, Robert J. D. Spurr², Thomas J. Pongetti¹, Gerard van Harten¹, Jonathan H. Jiang¹

¹ Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, 91109, USA

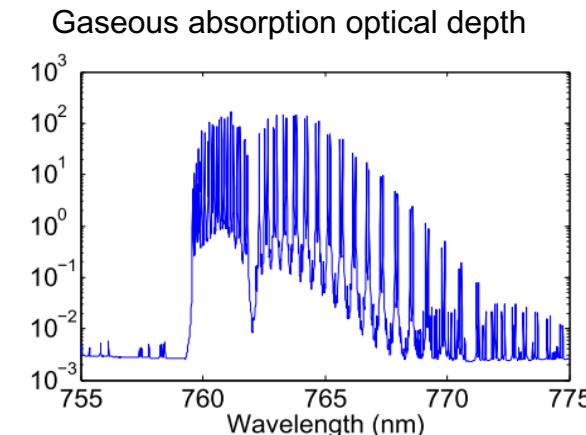
² RT Solutions Inc., Cambridge, MA, 02138, USA

* Points of Contact: myungje.choi@jpl.nasa.gov

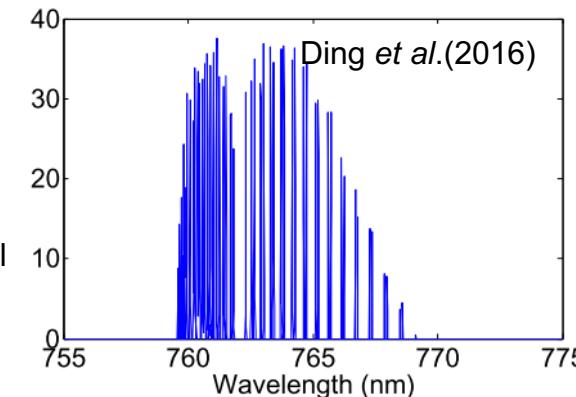
dejian.fu@jpl.nasa.gov

Aerosol vertical profile retrievals using O₂ A-band

- Measurement approach to help in obtaining aerosol vertical distribution information
 - High spectral resolution and signal to noise ratio
 - Linear polarization
 - Multi-viewing angles
 - Multi-spectral bands
- Current state of measurements focus on radiance-only.
 - Radiometers: MERIS, POLDER, EPIC, 3MI, MAIA
 - Spectrometers: GOME-2, SCIAMACHY, TANSO-FTS, OCO-2, CarbonSpec, TROPOMI, OCI
 - Xu *et al.*(2017)
- Joint radiance/polarization measurement can significantly increase information contents
 - Stam *et al.*(1999), Boesche *et al.*(2008), Wang *et al.*(2014), Ding *et al.*(2016)
 - Lack of theoretical/measurement analyses quantifying the impacts of spectral resolution, signal-to-noise ratio on aerosol profiling



Downward penetration altitude (km)

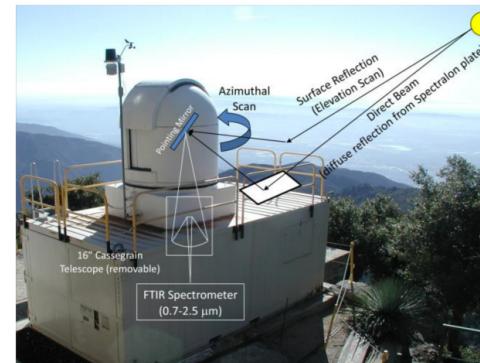


Objectives of this study

- Develop Observing System Simulation Experiment (OSSE) framework for information content analysis of aerosol profiling using O₂ NIR bands
 - Joint radiance/polarization, multiple viewing angles, multiple spectral bands
 - Spectral resolution, SNR
 - Versatile Aerosol scenarios and surface properties
 - Aerosols in planetary boundary layer over megacities
- Enable aerosol profiling measurements over LA basin using CLASR-FTS
 - Extend measurements from ${}^1\Delta$ -band to A-band
 - Linear polarization measurements with a high spectral resolution
 - Retrievals using measured radiometric and polarimetric spectra
- To inform the requirements/strategies of future missions

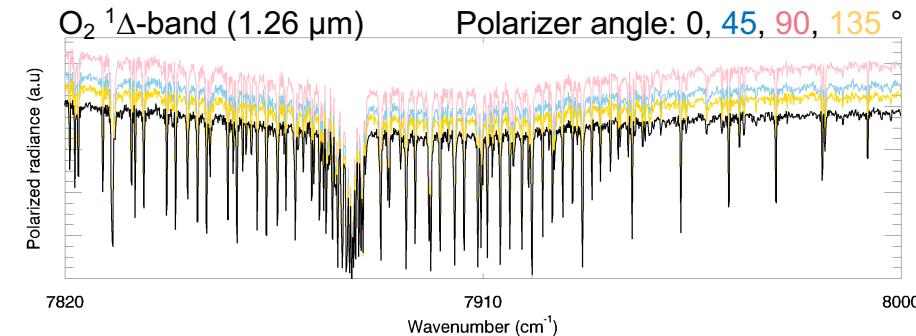
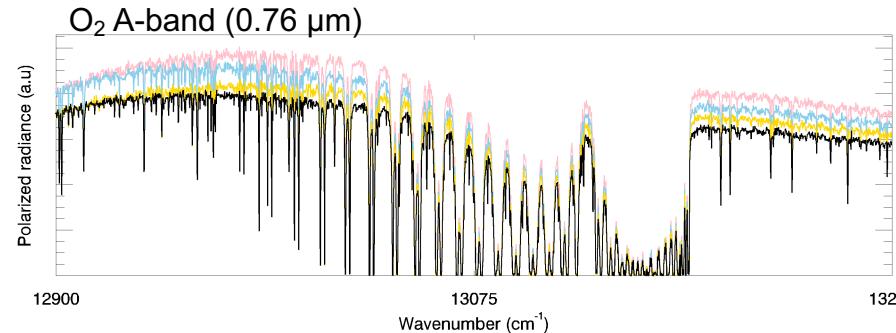
CLARS-FTS

Jet Propulsion Laboratory (JPL)'s
California Laboratory for Atmospheric Remote Sensing (CLARS) - Fourier transform spectrometer (FTS)



Fu et al. (2014)
Wong et al. (2015)
Zeng et al. (2018)

Sample spectra from CLARS-FTS spectropolarimetric measurement



Observing System Simulation Experiment (OSSE) framework

Climatology over LA basin

- Constraint information of aerosol and surface
- Seasonal/monthly ground-based/satellite products

RT simulation

- VLIDORT 2.7 (Spurr 2016)
 - Total radiance (I)
 - Linear polarization (Q, U)
 - Jacobian ($\frac{\partial y}{\partial x}$)

Simulated observation

- Instrument model
 - Instrument line shape function
 - Signal-to-noise ratio (SNR)
- Calibration uncertainty

Information contents and retrieval error

- Optimal estimation method (Rodgers 2000)
 - Degree of freedom for signal (DFS)
 - Posteriori error (or retrieval error)
 - Sensitivity to calibration uncertainty

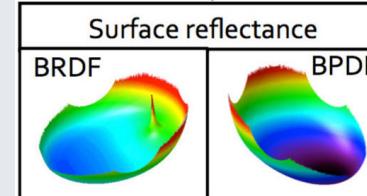
Aerosol/surface/gases climatology over LA basin

State vector $x = \{$

(each band) BRDF-isotropic, BRDF-volumetric, BRDF-geometric,
REFR-fine/coarse, REFL-f/c, PSD-radius-f/c, PSD-sigma-f/c, FMF,
AOD, Peak height, Half width,
Surface pressure, H₂O scale, Temperature shift

Surface BRDF/BPDF

- MODIS MAIAC
(Lyapustin *et al.*, 2018, AMT)
- POLDER GRASP
(Dubovik *et al.*, 2014, SPIE)
- Spectral relationship
from SCIAMACHY
(Tilstra *et al.*, 2017, JGR)



SCIAMACHY



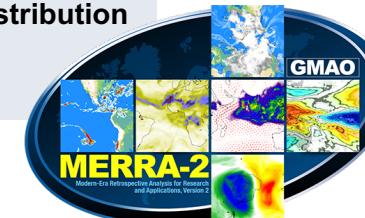
MODIS



POLDER

Pressure, Temperature, H₂O vertical distribution

- MERRA-2(Gelaro *et al.*, 2017, J. Clim)



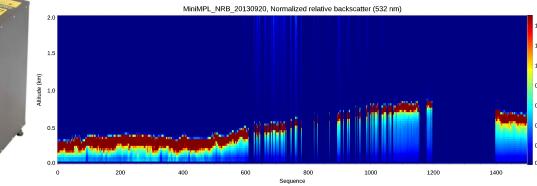
Aerosol microphysical properties

- AERONET over LA basin
(Holben *et al.*, 1998, RSE; Giles *et al.*, 2019, AMT)
- refractive indices, size distribution, AOD

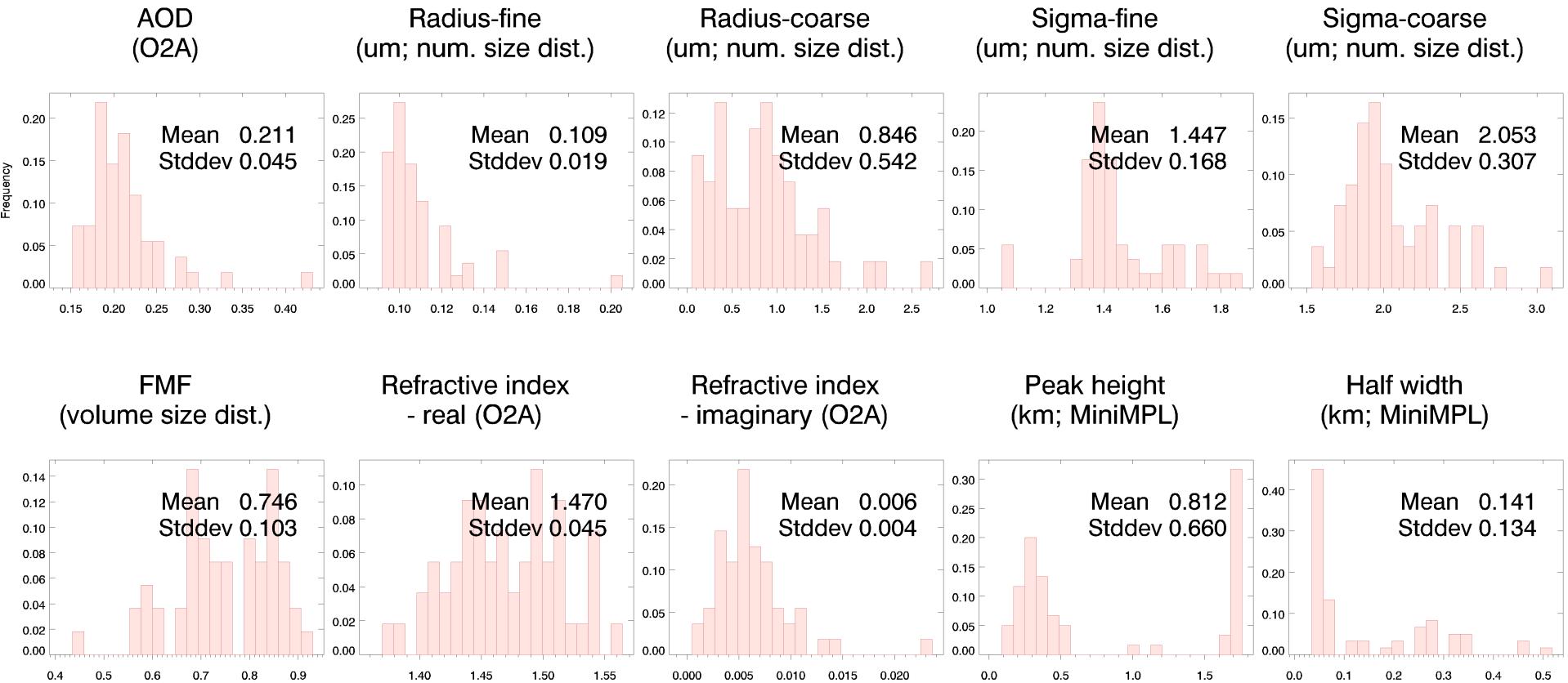


Aerosol vertical distribution

- Caltech MiniMPL
(Ware *et al.*, 2016, JGR)
- Peak height, half width



Climatological aerosol properties over LA basin (JJA)



Information contents quantification

DFS of aerosol profiling estimated for CLARS-FTS

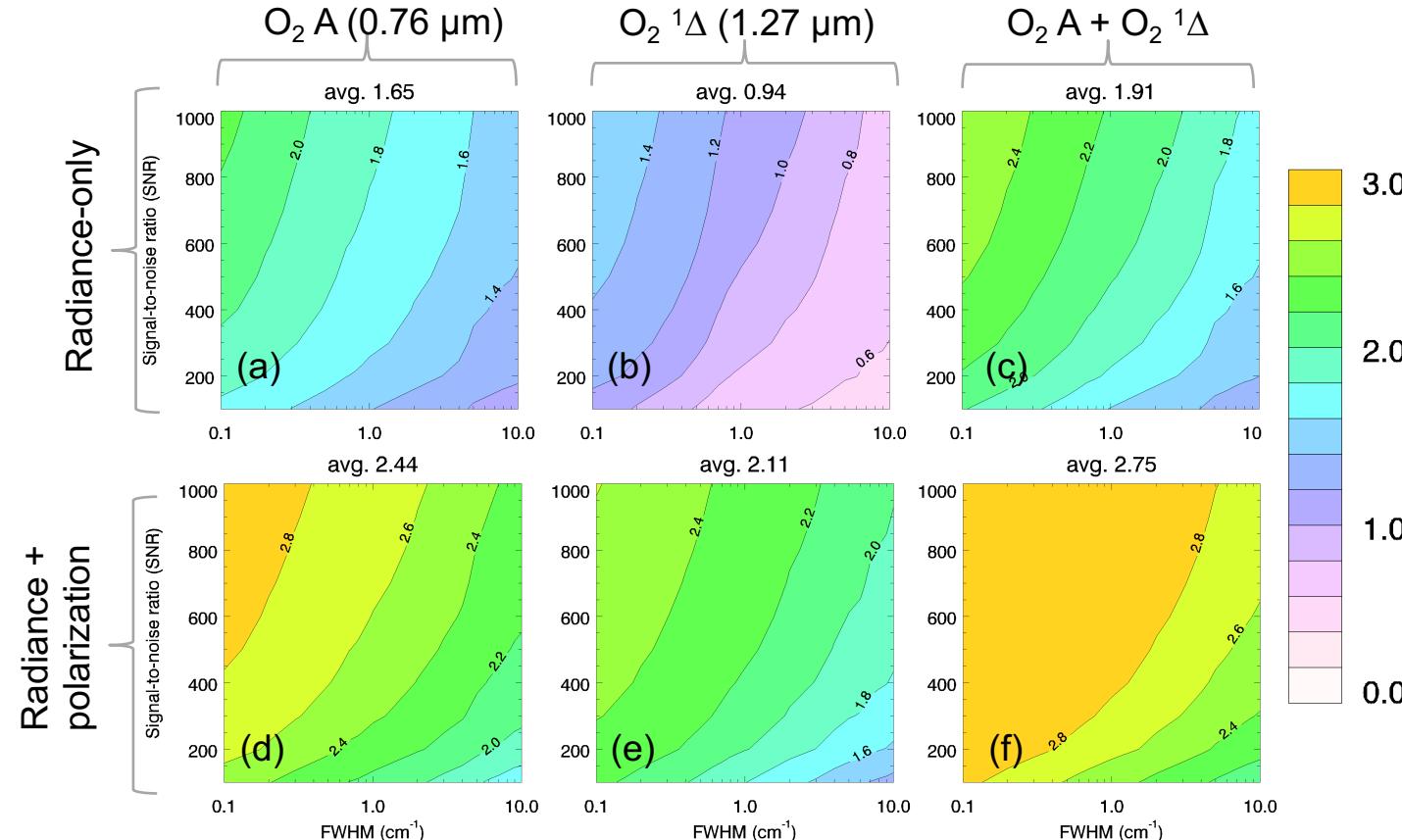
Averaged 50 aerosol loading scenarios:

AOD: 0.3, 1.0

PH: 0.2, 0.6, 1.0, 1.5, 2.0 km

HW: 0.2, 0.6, 1.0, 1.5, 2.0 km

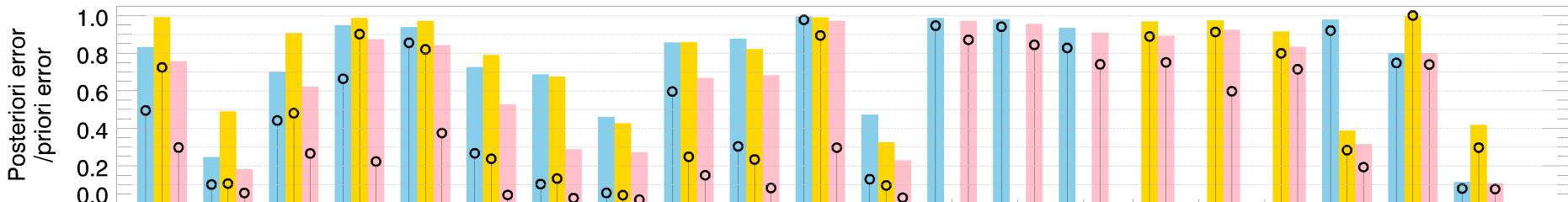
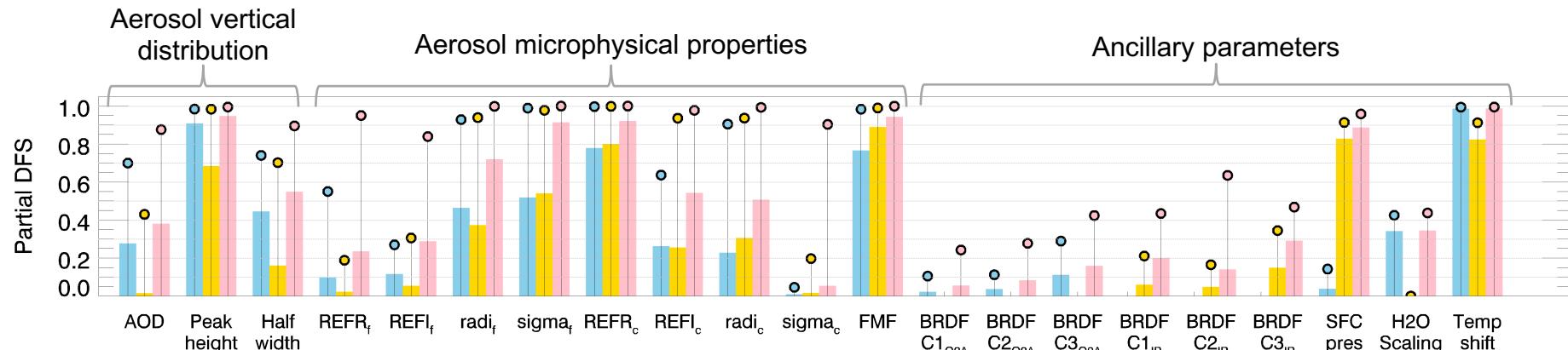
- Information:
 $\text{A-band} > ^1\Delta\text{-band}$
 - higher aerosol signal
 - A-band's lower surface reflectance
- Polarization adds **DFS~0.8** to aerosol profiling
- Insignificant increase two-bands vs. A-band



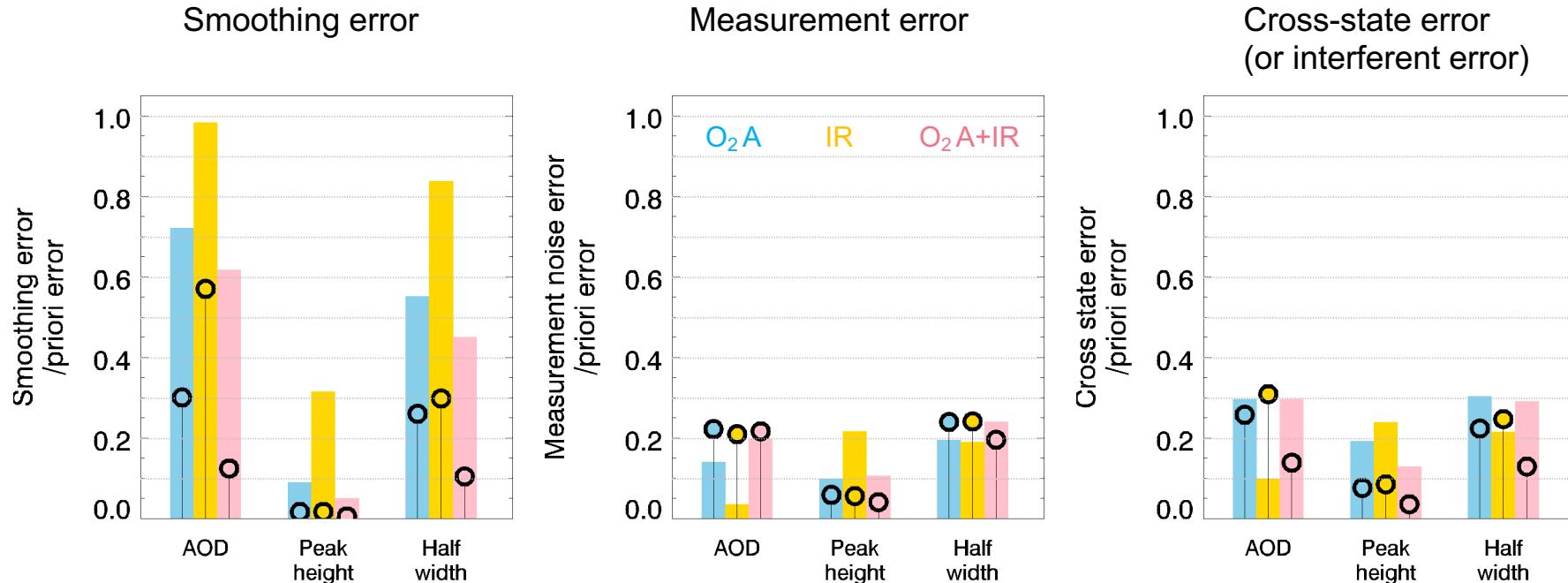
Estimated DFS and retrieval uncertainties

- FWHM 1.0 cm^{-1}
- SNR 300
- 50 different aerosol loading scenarios

Total DFS	O ₂ A	IR	O ₂ A+IR
Num. retrieval parameters	18	18	21
Radiance	6.4	6.0	10.2
Radiance + Polarization	10.8	11.1	16.3

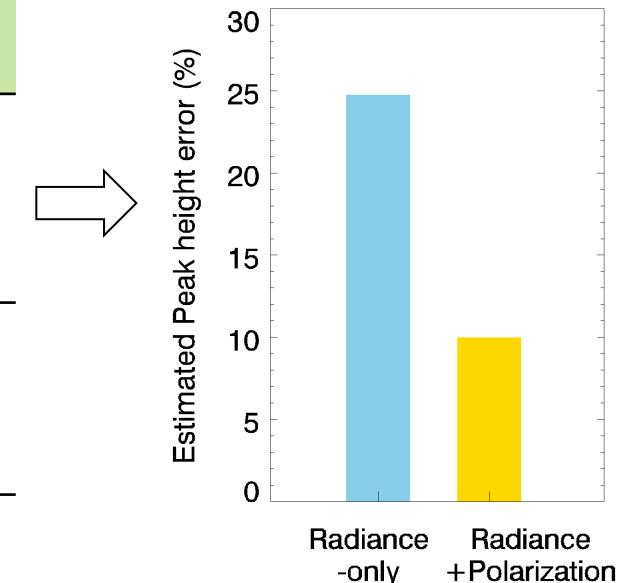


Estimated attribution of retrieval uncertainty



Improved information contents using polarization (CLARS-FTS; O₂A)

Geophy. Quantities		Radiance-only	Radiance + Polarization
Aerosol profiling	AOD	★★	★★★★★
	Peak height	★★★★★	★★★★★
	Half width	★★★	★★★★
Aerosol microphysical properties	Size distribution	★★	★★★★
	Refractive indices	★★	★★★★
Surface reflectance	BRDF	★	★



Joint spectrally-resolved, linear polarimetric measurements

- significantly enhance information contents of aerosol profiling and microphysical properties.
- reduce retrieval errors of all parameters, most significantly for peak height, whose DFS about 1 for both radiance-only and joint radiance/polarization.

Information contents of O₂ A-band (CLARS vs Satellite)

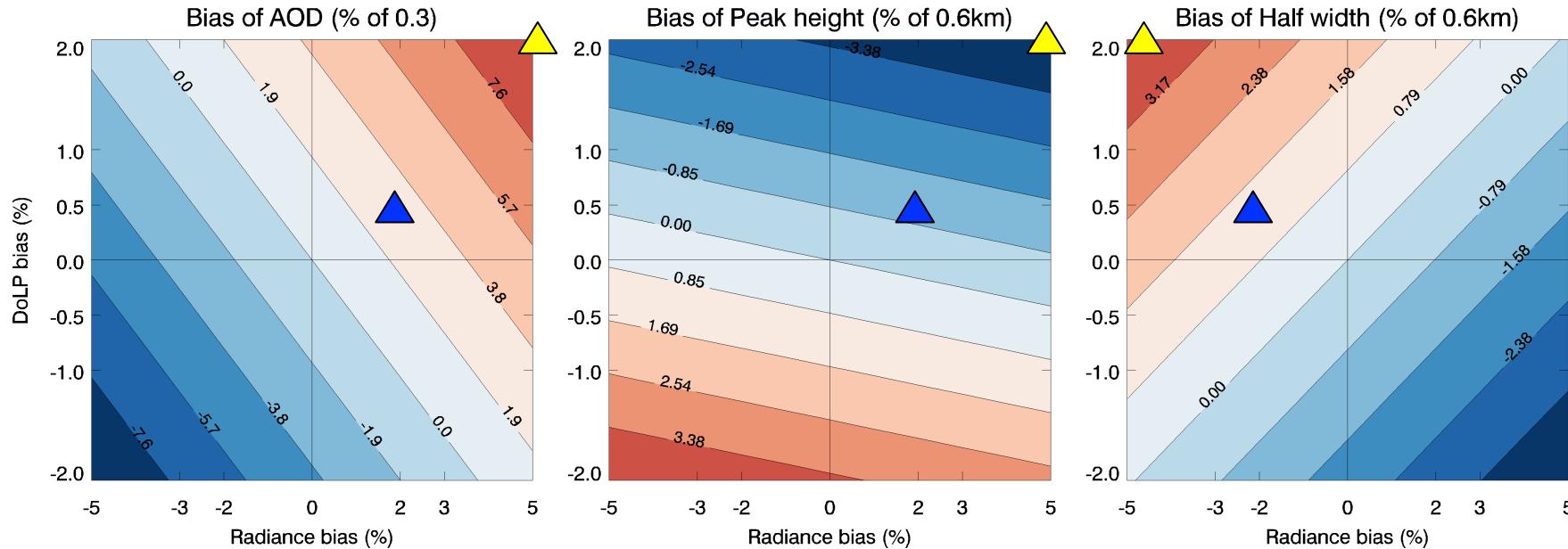
DFS of vertical distribution (AOD, Peak height, Half width)	CLARS	Satellite		
	VZA 83°	Nadir	3 angles	9 angles (MAIA-like)
	High spectral resolution (FWHM 1 cm ⁻¹ ; SNR 300)			Band-averaged (15 nm; SNR 300)
Radiance	1.63	0.86	1.66	0.43
Radiance + Polarization	2.42	1.70	2.68	0.96

- Among high spectral resolution measurements:
 - CLARS single viewing geometry ≈ satellite 3 viewing angles (0, ±20°) > satellite nadir-only
- Band-averaged O₂ A-band-only: insufficient information for aerosol profiling even employing multi-angle and polarization.
 - Combining additional spectral bands (UV-VIS-IR) increases information of aerosol microphysical properties, thus enhancing profiling information.

Estimated impacts of calibration uncertainty on aerosol retrievals

- $\Delta\hat{x} = G\Delta y$
- Scenario
 - CLARS geometry
 - O₂ A-band only
 - Joint radiance/polarization

Calibration uncertainty		Estimated retrieval bias		
I	DoLP	AOD 0.3	Peak height 0.6 km	Half width 0.6 km
2%	0.005 (0.5%)	3.2%	1.2%	1.7%
5%	0.02 (2%)	9.5%	4.2%	3.6%



Summary

Developed an algorithmic tool, performed OSSEs to quantify the information contents and retrieval uncertainties for both ground-based and LEO satellite viewing geometries across a suite of aerosol scenarios.

When combining spectrally resolved, radiance and linear polarization measurements, the degree of freedom (DFS) for aerosol profiling retrievals significantly increase by ~ 0.8 , while the retrieval uncertainties reduce, for both ground-based and LEO satellite measurements.

CLARS measurements can provide more information than satellite-nadir measurements – DFS enhances ~ 0.7 , benefiting from its viewing geometry.

Next steps:

- Detail polarimetric calibration of CLARS-FTS
- Retrievals of aerosol vertical distribution using calibrated CLARS-FTS radiance/polarization spectra.
- Validation via independent measurements (Lidar, TROPOMI, etc.)



Thanks for your attention!

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